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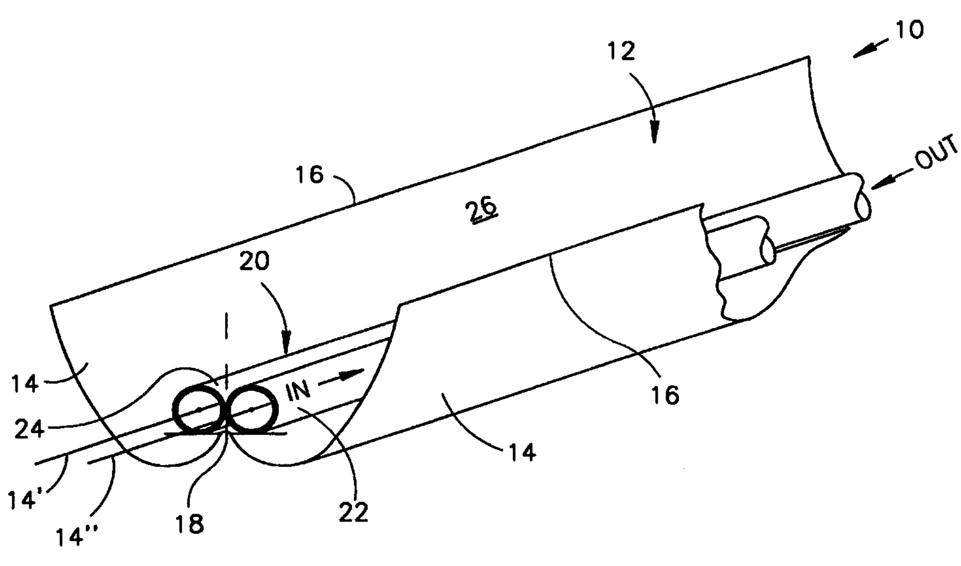

(57) Abstract

A solar collector unit which includes a trough–shaped compound parabolic concentrator. The concentrator is formed of two integral side–by–side portions, each having a compound parabolic cross–sectional configuration which extends inwardly from a free edge and terminates at a common apex, thereby defining a ridge portion extending along the length of the trough–shaped concentrator. The concentrator has a generally omega–shaped cross–sectional configuration. The concentrator also defines a focal region parallel to the ridge portion. The solar collector unit also includes an elongate receiver construction extending along the length of the concentrator in the focal region, thereby to receive solar energy focused thereat by the concentrator. The elongate receiver construction has an arrangement of parallel, interconnecting conduits for carrying a throughflow of a fluid to be heated. The ridge portion of the concentrator intersects with a tangential plane common to at least a pair of the conduits, thereby substantially preventing gap loss thereat.

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SOLAR COLLECTOR

FIELD OF THE INVENTION

The present invention relates generally to solar energy collection and, in particular, to the use of compound parabolic concentrators for this purpose.

BACKGROUND OF THE INVENTION

Many solar energy collector systems are known in the art, particularly those useful in energy storage schemes that are intended to replace more conventional electrical power generation plants.

Many of the existing solutions, however, are not suitable for more localized, smaller scale use, including those which may merely supplement electrical power connections, such as heating and/or cooling of homes and businesses, as many of these systems are prohibitively expensive, due to the fact that their efficiency is due, at least in part, to their having mechanisms which enable them to track the movement of the sun.

By way of example, many homes and businesses in Israel have flat panel solar collectors, which are essentially plate conduits coated with black paint, and which heat water passing therethrough. These are simple, unsophisticated, inexpensive structures which, while not providing an energy solution on their own, act as a useful supplement to the more conventional, electrically powered water heating devices. A disadvantage of these systems, however, is that they are inefficient and have a large heat emission surface area, giving rise to large heat losses, which increase in accordance with increases in temperature.

In the field of more sophisticated non-tracking systems, compound parabolic concentrators (CPCs) are known. An advantage of CPCs is that they do not require physical tracking, as this is effectively replaced by the geometric design of the concentrating surface.

One type of CPC is generally trough-shaped, and the absorber is a tubular absorber, arranged along the focal axis of the CPC. Conventional CPCs are characterized, however, by heat looses which emanate from radiation striking an inward-facing, reflective surface thereof, and being reflected several times prior to being focused on the absorber; losses in concentrated energy during reflection are thus generally multiplied prior to the energy reaching the absorber. Further heat losses are caused by a high emissivity of the absorber, and low transmissivity of

glass surrounding the absorber, and well known gap losses, due to the geometric design of the CPC.

An indication of the state of the art in the field of CPCs may be obtained by referring to US Patent No. 4,387,961 to Winston, entitled "Compound Parabolic Concentrator with Cavity for Tubular Absorbers." This reference describes a compound parabolic concentrator which has a V-shaped cavity in which an optical receiver is located, and wherein the cavity redirects all energy entering between the receiver and the cavity structure onto the receiver, if the optical receiver is positioned at a distance of no greater than 0.27 x the cavity radius, from the cavity.

US Patent No. 5,5673,684 to Myles, III et al, teaches a tracking solar energy concentrating system, having a primary receiver, and a plurality of secondary receivers, each secondary receiver having a compound parabolic shape.

A further problem with solar concentrator systems employing tubular absorbers, in general, is the fact that there are multiple energy losses, which, apart from the specific source of loss mentioned above in connection with CPCs, may include gap loss, a relatively low solar absorption of the absorber, and a high emissive loss thereof, due to the relatively large ratio of surface area to cross-sectional area. One way in which it has been sought to reduce these problems, is by locating the absorber inside a glass tube, although a further potential problem is thus created, due to the fact that the tube must have a very high transmissivity.

SUMMARY OF THE INVENTION

The present inventions seeks to provide a high performance solar compound parabolic concentrator (CPC) and improved solar collector unit and array using the high performance CPC, overcoming disadvantages of known art.

There is thus provided, in accordance with a preferred embodiment of the invention, a solar collector unit which includes:

a trough-shaped compound parabolic concentrator formed of two integral side-by-side portions, each having a compound parabolic cross-sectional configuration which extends inwardly from a free edge and terminates at a common apex, thereby to define a ridge portion extending along the length of the trough-shaped concentrator, and such that the concentrator has a generally omega-shaped cross-sectional configuration, and the concentrator defining a focal region parallel to the ridge portion; and

an elongate receiver construction extending along the length of the concentrator in the focal region, thereby to receive solar energy focused thereat by the concentrator, and having an arrangement of parallel, interconnecting conduits for carrying a throughflow of a fluid to be heated,

wherein the ridge portion of the concentrator intersects with a tangential plane common to at least a pair of the conduits, thereby substantially preventing gap loss thereat.

Further in accordance with a preferred embodiment of the present invention, the concentrator and receiver construction are located within a housing of which at least a portion is solar energy transmissive.

Further in accordance with a preferred embodiment of the present invention, there is also provided an anti-reflective coating on the solar energy transmissive portion.

Further in accordance with a preferred embodiment of the present invention, the housing includes an elongate, solar energy transmissive tube, for housing a single concentrator and tube.

Further in accordance with a preferred embodiment of the present invention, the housing includes a generally shallow, prismatic shaped housing for holding a plurality of concentrators and receiver constructions.

Preferably, the housing is sealed and evacuated, and is filled with a predetermined gas.

Further in accordance with a preferred embodiment of the present invention, the concentrator has an inward-facing reflective surface, and wherein the solar collector unit includes at least a predetermined one of a first coating, formed on the inward-facing reflective surface, having high solar energy reflection; and a second coating, formed on the conduits, having high solar absorptivity and low emissivity.

In accordance with an alternative embodiment of the invention, there is provided a solar collector which includes

a plurality of elongate solar collector units as described above, disposed in a coplanar side by side arrangement, so as to have a plurality of the concentrators and a corresponding plurality of the receiver conduit arrangements;

a support for supporting the plurality of elongate solar collector units, in the coplanar side by side arrangement;

a main fluid inlet conduit for admitting to the plurality of conduit arrangements a fluid to be heated; and

a main fluid outlet conduit for facilitating discharge from the plurality of conduit arrangements a fluid heated therein.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more fully understood and appreciated form the following detailed description, taken in conjunction with the drawings, in which:

Fig. 1A is a fragmented pictorial representation of an improved solar collector unit, constructed in accordance with a preferred embodiment of the present invention;

Fig. 1B is an enlarged end view of the collector unit of Fig. 1A;

Fig. 2A is a plan view of a solar collector serial array, constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 2B is a cross-sectional view taken along line B-B in Fig. 2A;

Fig. 3A is a schematic view showing the conduit array of Figs. 2A and 2B positioned in the housing therein;

Fig. 3B is an enlarged detailed view of the inlet and outlet, respectively, of an absorber conduit arrangement, indicated by arrow B in Fig. 3A;

Fig. 3C is an enlarged detailed view of the bend portion of an absorber conduit arrangement, indicated by arrow C in Fig. 3A;

Fig. 4A is a plan view of a solar collector parallel array, constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 4B is a cross-sectional view taken along line B-B in Fig. 4A;

Fig. 5A is an enlarged detailed plan view of the inlet and outlet, respectively, of an absorber conduit arrangement, indicated by arrow 5 in Fig. 4A;

Fig. 5B is a sectional view of the detail seen in Fig. 5A, taken along line B-B thereon;

Fig. 6A is a schematic side view of the solar collector unit of Figs. 1A and 1B, but having a tubular glass housing, in accordance with a further embodiment of the present invention;

Fig. 6B is an enlarged cross-sectional view of the collector unit of Fig. 6A, taken along line B-B therein;

Fig. 7A is a fragmented pictorial representation of an improved solar collector unit, having three absorber conduits, in accordance with an alternative embodiment of the present invention;

Fig. 7B is an enlarged end view of the collector unit of Fig. 7A; and

Fig. 8 is a cross-sectional view of a collector unit which is generally similar to that illustrated in Fig. 6B, but wherein the concentrator has a divided omega-shaped cross-sectional configuration, in accordance with a further embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to Fig. 1A, there is seen, in pictorial form, an improved solar collector unit, referenced generally 10, constructed and operative in accordance with a preferred embodiment of the present invention. Unit 10 includes a trough-shaped CPC (compound parabolic concentrator), referenced generally 12, which, as seen also in Fig. 1B, is formed of two integral side-by-side portions 14. Portions 14 may be formed separately, or of a single piece of material. Each portion 14 has a CPC configuration which extends inwardly from a free edge 16 and terminates at a common apex 18, so as to define thereat a ridge portion extending along the length of the concentrator, and such that the concentrator has a generally omega-shaped cross-sectional configuration.

Concentrator 12 defines a defines a focal region whose center of area may be indicated generally by respective axes 14' and 14" parallel to ridge portion 18. Collector unit 10 also includes an elongate receiver construction, referenced generally 20, which is formed, in the present embodiment, of an arrangement of first and second, parallel interconnecting conduits, respectively referenced 22 and 24, for carrying a throughflow of a fluid to be heated, in the directions indicated in Fig. 1A by the arrows labeled IN and OUT. The pair of conduits 22 and 24 are made of highly heat transmissive materials, preferably metal. In accordance with a preferred embodiment of the invention, the conduits 22 and 24 extend along respective axes 14' and 14", such that optical energy impinging on an inward-facing, reflective surface, referenced 26, is reflected to conduits 22 and 24, and absorbed by the fluid flowing therethrough.

Referring now briefly to Figs. 7A and 7B, there is shown a solar collector unit, referenced generally 110, which is similar to unit 10 of Figs. 1A and 1B in many respects, and in which all of the portions and components having counterparts shown and described herein in conjunction with Figs. 1A and 1B, are indicated by similar reference numerals but with the addition of the prefix "1".

The only difference between the present unit 110 and unit 10 of Figs. 1A and 1B, is in the number of conduits forming receiver construction 120. In the present

embodiment, there is provided an arrangement of three parallel conduits, respectively referenced 122, 124 and 125, which are arranged along respective axes, 114", 114', and 114"'. It is seen that, in addition to gap loss being prevented between surface 26 and conduits 122 and 124, conduit 125 is arranged so as to share a common tangent plane 129 with conduits 122 and 124, such that gap loss is prevented therebetween, also.

It will further be appreciated that additional conduits may be provided, as long as these conduits are arranged along mutually common tangent planes so as to prevent gap loss therebetween, and thereby maximizing the efficiency thereof.

Referring now once again to Figs. 1A and 1B, in the present invention, the fluid employed may be any suitable liquid, such as water or oil, or any suitable gas, such as steam, air or argon.

An important feature ofthe present invention is that concentrator 12 and receiver construction 20 are arranged so as to eliminate gap loss therebetween, thereby raising the efficiency of the present invention when compared with known devices. In particular, and referring no particularly to Fig. 1B, it is seen that absorber conduits 22 and 24 share a common tangential plane, indicated in end profile by line 28, and that, in order to eliminate gap loss, the conduits 22 and 24 and concentrator 12 are arranged such that ridge portion 18 thereof preferably intersects with plane 28, at least touching it but preferably projecting therethrough. This ensures that all optical energy passing beneath absorber conduits 22 and 24 is intercepted by a concentrator portion thereat, after which the energy is reflected to one of the absorber conduits.

Referring now to Figs. 2A and 2B, it is seen that, in accordance with a preferred embodiment of the invention, a plurality of solar collector units 10 is disposed in a coplanar side by side arrangement, so as to form a solar collector array, referenced generally 30. The array 30 is arranged in a typically shallow, generally prismatic housing 32, which, as seen in Figs. 2B and 3A, preferably includes a plurality of suitably configured supports 34, or other supporting means, arranged for supporting concentrators 12 and absorber conduits 22 and 24 associated therewith.

Referring now also to Figs. 3A-3C, in accordance with a preferred embodiment of the invention, each arrangement of absorber conduits has an inlet 36 (Fig. 3B) associated with first conduit 22, and an outlet 38 associated with second conduit 24, and a bend portion 40 (Fig. 3C) connecting between the two

conduits. There is also provided a main fluid inlet conduit 42 (Fig. 3A) which defines an inlet for array 30, and a fluid outlet conduit 44 (Fig. 3A) which defines an outlet for the array 30. It is thus seen that the absorber conduit arrangements are connected in series, such that an unheated fluid entering array 30 via main fluid inlet conduit 42, flows through all the conduit arrangements in series, until it reaches fluid outlet conduit 44, thereafter being discharged, for use.

Referring now briefly to Figs. 4A and 4B, there is provided a solar collector array, referenced generally 50, constructed in accordance with an alternative embodiment of the invention. Array 50 is generally similar to array 30, except for the fact that the conduit arrangements are connected in parallel, and not in series as in array 30. Array 50 is thus not specifically described herein, except with regard to differences between array 30 and array 50. Portions of array 50 having counterpart portions in array 30, are indicated in Figs. 4A and 4B by the same reference numerals, and are not specifically described herein except as may be necessary to understand the present embodiment.

Referring now also to Figs. 5A and 5B, there are provided a main fluid inlet conduit 52 (Fig. 5B) and a main fluid outlet conduit 54 (Fig. 5B). Main fluid inlet conduit 52 functions as a manifold connected in parallel to the inlets 36 of all the first conduits 22, and main outlet fluid conduit 54, also function as a manifold, and is connected in parallel to the outlets 38 of all the second conduits 24. It is thus seen that the absorber conduit arrangements are arranged in parallel, such that an unheated fluid entering array 50 via main fluid inlet conduit 52, flows through all the first conduits 22 substantially simultaneously, and returns via second conduits 24 to main outlet fluid conduit 54, for subsequent discharge therefrom.

Referring now once again to Figs. 2B and 4B, in accordance with a preferred embodiment of the invention, housing 32 includes a solar energy transmissive panel 32', formed typically of high solar energy transmissive glass. An advantage of this is that it reduces convection heat losses, and also prevents dust and other forms of optical contamination from accumulating on the solar collector units 10, thereby reducing maintenance.

In accordance with a preferred embodiment of the invention, panel 32' is provided with a durable, solar anti-reflective coating, such as produced by the present Applicants.

Preferably, panel 32' is sealed to the remainder of housing 32, so as to facilitate provision of a predetermined atmosphere inside the housing, which may be

evacuated or, alternatively may be filled with inert or other gases, such as argon, carbon dioxide, nitrogen, or krypton, for example, so as to prevent the accumulation of condensation on any of the optical elements, while substantially reducing convection and conduction heat losses.

Referring now to Figs. 6A and 6B, rather than housing the entire solar collector array in a single, sealed housing, each solar collector unit 12 may be housed separately in a tubular housing 62. The housing 62 is preferably also formed of a highly solar energy transmissive glass, and has a closed end 64, and an open end 66, which is preferably sealed by means of a suitably formed sealing cap 68. As with housing 32 and panel 32' above, it will be appreciated that the interior of the tubular housing 62 may be evacuated or filled with a preferred gas. It will be appreciated that, due to possible large variations in working temperatures of the unit 12, a space 'S' is left between bend portion 40 of the absorber 20, and closed end 64 of the housing 62, thereby to prevent damage thereto arising from thermal expansion of the absorber conduits 22 and 24.

Referring now once again to Figs. 1A-4B, 6A, and 6B, the inward-facing, reflective surface 26 of concentrator 12 preferably has provided thereon a solar energy reflective coating which, by way of example, may be silver-based. A suitable coating preferably has a reflectivity coefficient ϕ as high as approximately 97%.

Preferably there is also provided an additional further coating, which has a high solar absorptivity and low emissivity, on conduit lengths 22 and 24. By way of example only, this coating may be a cermet sputtering based coating, having an absorptivity coefficient $\alpha \approx 97$, and an emissivity coefficient $\varepsilon \approx 0.04$, at a working temperature $T = 200\ ^{\circ}C$.

The above combination of components and materials are stable in temperatures of up to 450 °C, and facilitate system working temperatures ("stagnation" working temperature) of up to 400 °C. It will be appreciated that this is substantially higher than the maximum working temperatures known in the art, and thus provides for a system that is considerably more efficient than previously known for non-tracking solar collectors generally, and those employing CPCs, in particular.

Referring now to Fig. 8, there is shown, in cross-sectional view, a solar collector unit, referenced generally 210, which is similar to unit 10 of Figs. 1A and 1B in many respects, and in which all of the portions and components having counterparts shown and described herein in conjunction with Figs. 1A and 1B, are indicated by similar reference numerals but with the addition of the prefix "2". The

principle difference between unit 210, shown herein, and unit 10 (Figs. 1A and 1B), is that receiver construction 220 is formed by a pair of conduits 222 and 224 which, while mutually parallel, are spaced apart by a predetermined lateral spacing 'S'. While this arrangement facilitates a simpler method of production of solar collectors in accordance with the present invention, CPC 212 of the present embodiment is configured so as to eliminate loss of solar energy that would otherwise occur through the gap formed between the conduits 222 and 224.

Accordingly, CPC 212 is provided with a divided generally omega-shaped cross-sectional configuration, which is generally similar to the configuration of CPC 12 (Figs. 1A and 1B), but wherein the side-by side portions 214 of CPC 212 terminates in an apex region, referenced generally 217, which typically has a triangular configuration, and itself terminates in an apex 218. It will also be noted that apex portion 217 extends between conduits 222 and 224, thereby to intersect with plane 228, and so as to extend substantially therethrough. The height of the apex 218 is a function of the acceptance angle α and the magnitude of spacing S, and is arranged such that any optical energy passing between conduits 222 and 224 is intercepted by one of the reflective surfaces 217a or 217b of apex portion 217, is reflected directly onto conduits 222 or 224, thereby substantially preventing gap loss.

Furthermore, while, as in the embodiment of Figs. 6A and 6B, collector unit 212 may be housed in a separate tubular housing 62, this need not be the case, and is shown by way of non-limiting example only.

It will be appreciated by persons skilled in the art that the scope of the present invention is not limited by what has been shown and described hereinabove. Rather the scope of the present invention is limited solely by the claims, which follow.

CLAIMS

1. A solar collector unit which includes:

a trough-shaped compound parabolic concentrator formed of two integral side-by-side portions, each having a compound parabolic cross-sectional configuration which extends inwardly from a free edge and terminates at a common ridge portion extending along the length of said trough-shaped concentrator, and such that said concentrator has a generally omega-shaped cross-sectional configuration, wherein said concentrator defines a focal region parallel to said ridge portion; and

an elongate receiver construction extending along the length of said concentrator in said focal region, thereby to receive solar energy focused thereat by said concentrator, and having an arrangement of parallel, interconnecting conduits for carrying a throughflow of a fluid to be heated,

wherein said ridge portion of said concentrator intersects with a tangential plane common to at least a pair of said conduits, thereby substantially preventing gap loss thereat.

2. A solar collector unit according to claim 1, and wherein said concentrator and receiver construction are located within a housing of which at least a portion is solar energy transmissive.

3. A solar collector unit according to claim 2, and including an anti-reflective coating provided on said solar energy transmissive portion.

4. A solar collector according to claim 2, wherein said housing includes an elongate, solar energy transmissive tube, for housing a single concentrator and tube.

5. A solar collector according to claim 2, wherein said housing includes a generally shallow, prismatic shaped housing for holding a plurality of concentrators and receiver constructions.

6. A solar collector unit according to claim 2, wherein said housing is a sealed housing.

7. A solar collector unit according to claim 6, wherein the interior of said housing is evacuated.

8. A solar collector unit according to claim 6, wherein the interior of said housing is filled with a predetermined gas.

9. A solar collector unit according to claim 1, wherein said concentrator has an inward-facing reflective surface, and wherein said solar collector unit includes at least a predetermined one of a first coating, formed on said inward-facing reflective surface, having high solar energy reflection; and a second coating, formed on said conduits, having high solar absorptivity and low emissivity.

10. A solar collector unit according to claim 9, wherein said reflective coating has a reflectivity coefficient $\phi \approx 97\%$.

11. A solar collector unit according to claim 9, wherein said high solar absorptivity and low emissivity coating has an absorptivity coefficient $\alpha \approx 97$; and an emissivity coefficient $\varepsilon \approx 0.04$ at a working temperature $T = 200\ ^{o}C$.

12. A solar collector unit according to claim 9, wherein said first and second coatings are stable in working temperatures of up to approximately 450 ^{o}C.

13. A solar collector unit according to claim 1, wherein said receiver construction includes at least two conduits.

14. A solar collector according to claim 13, wherein said arrangement of conduits includes at least first, second and third conduits, wherein said first and second conduits define a first tangential plane common thereto, which is intersected by said ridge, and said first, second and third conduits define a second tangential plane, thereby to prevent gap loss therebetween.

15. A solar collector which includes:

a plurality of elongate solar collector units as claimed in claim 1, disposed in a coplanar side by side arrangement, so as to have a plurality of said concentrators and a corresponding plurality of said receiver conduit arrangements;

a support for supporting said plurality of elongate solar collector units, in said coplanar side by side arrangement;

a main fluid inlet conduit for admitting to said plurality of conduit arrangements a fluid to be heated; and

a main fluid outlet conduit for facilitating discharge from said plurality of conduit arrangements a fluid heated therein.

16. A solar collector according to claim 15, wherein each said conduit arrangement has at least one inlet and least one outlet, and said conduit arrangements are arranged in parallel,

and wherein said main fluid inlet conduit is a fluid supply manifold connected to said inlet of each said conduit arrangement, and said main fluid outlet conduit is a heated fluid discharge manifold connected to said outlet of each said conduit arrangement.

17. A solar collector according to claim 15, wherein each said conduit arrangement has an inlet and an outlet and said plurality of conduit arrangements defines an array of said conduit arrangements connected in series so as to have an array inlet and an array outlet,

and wherein said main fluid inlet conduit is connected to said array inlet, and said main fluid outlet conduit is connected to said array outlet.

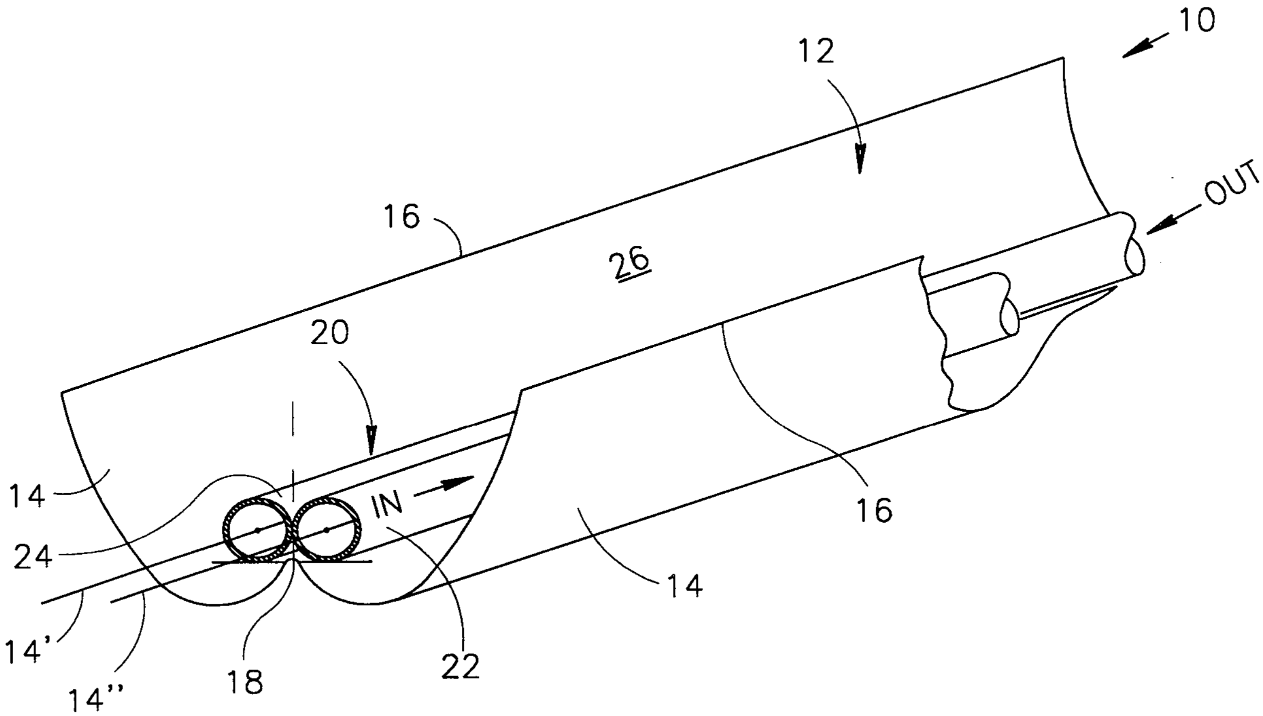

10
12
OUT
16
26
20
14
IN
24
16
14
14'
18
22
14''

FIG.1A

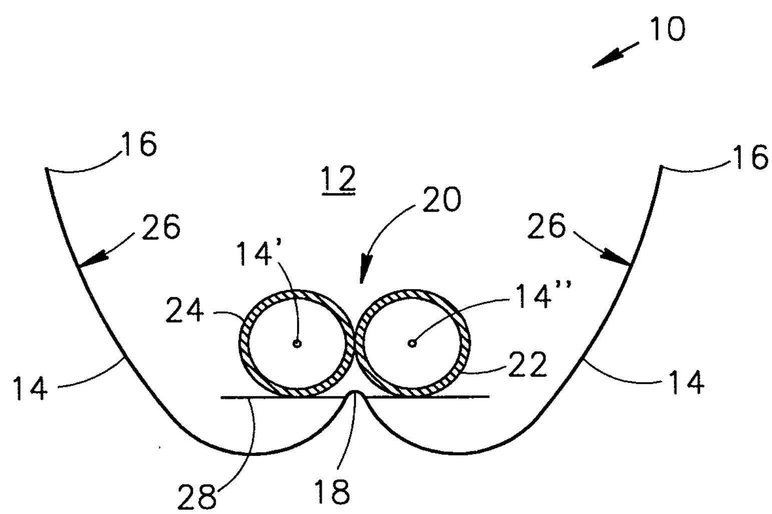

10
16
12
20
16
26
26
14'
24
14''
22
14
14
28
18

FIG.1B

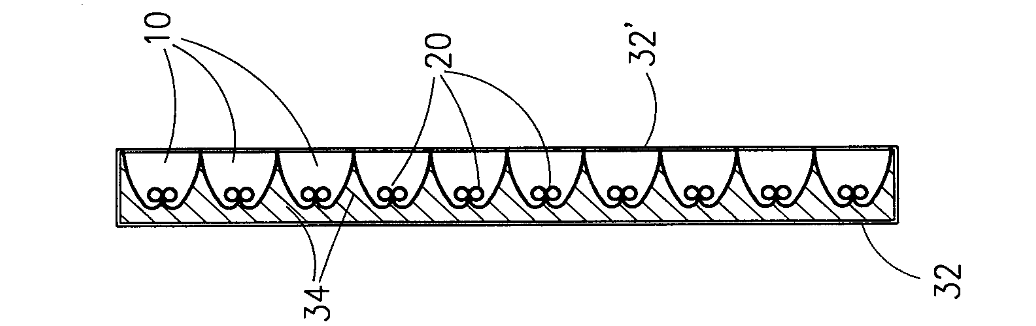


FIG.2B

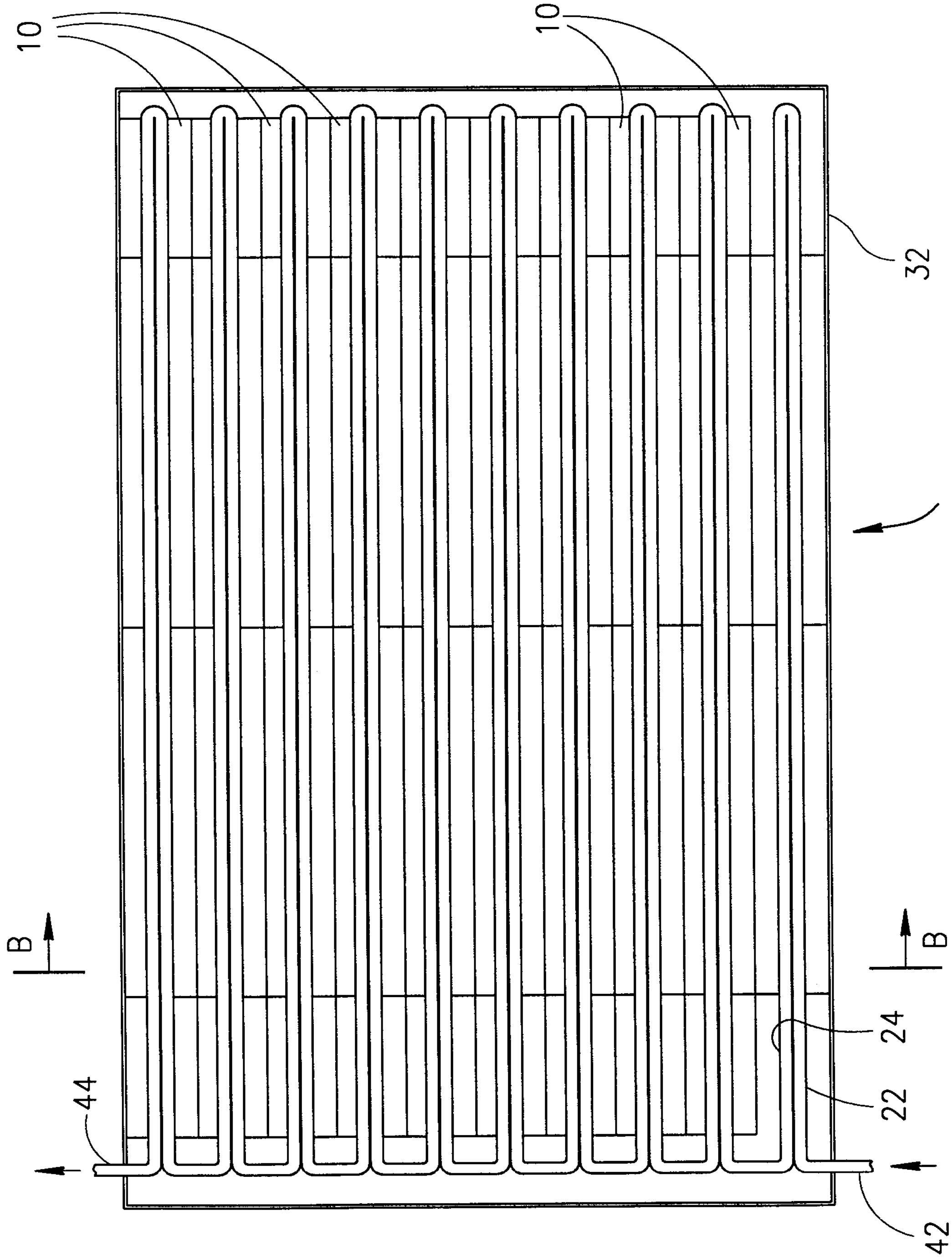


FIG.2A

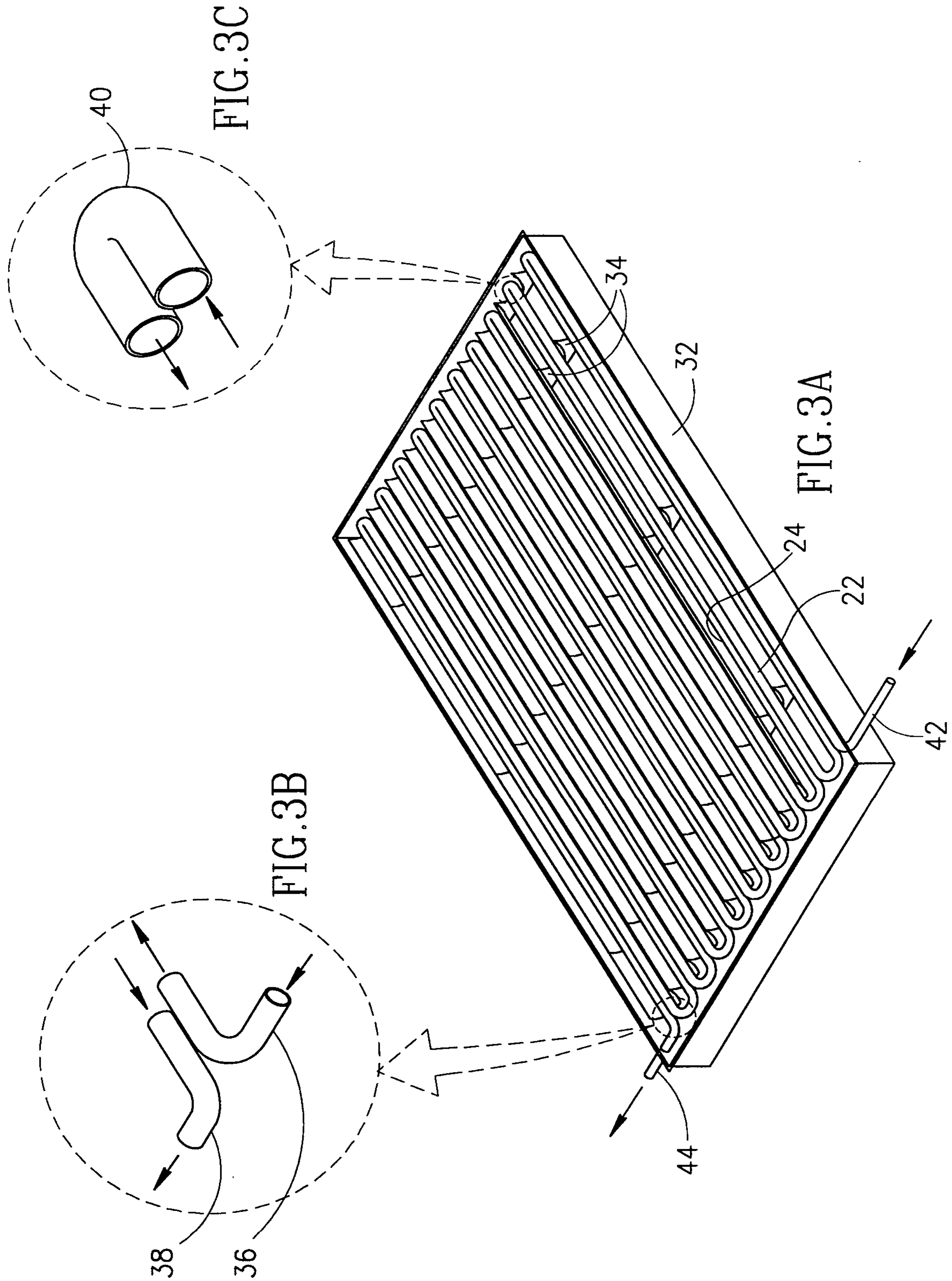


FIG.3A

FIG.3B

FIG.3C

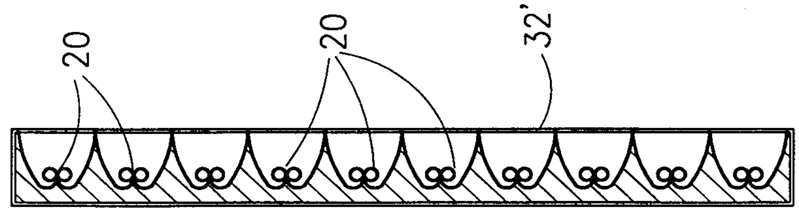


FIG.4B

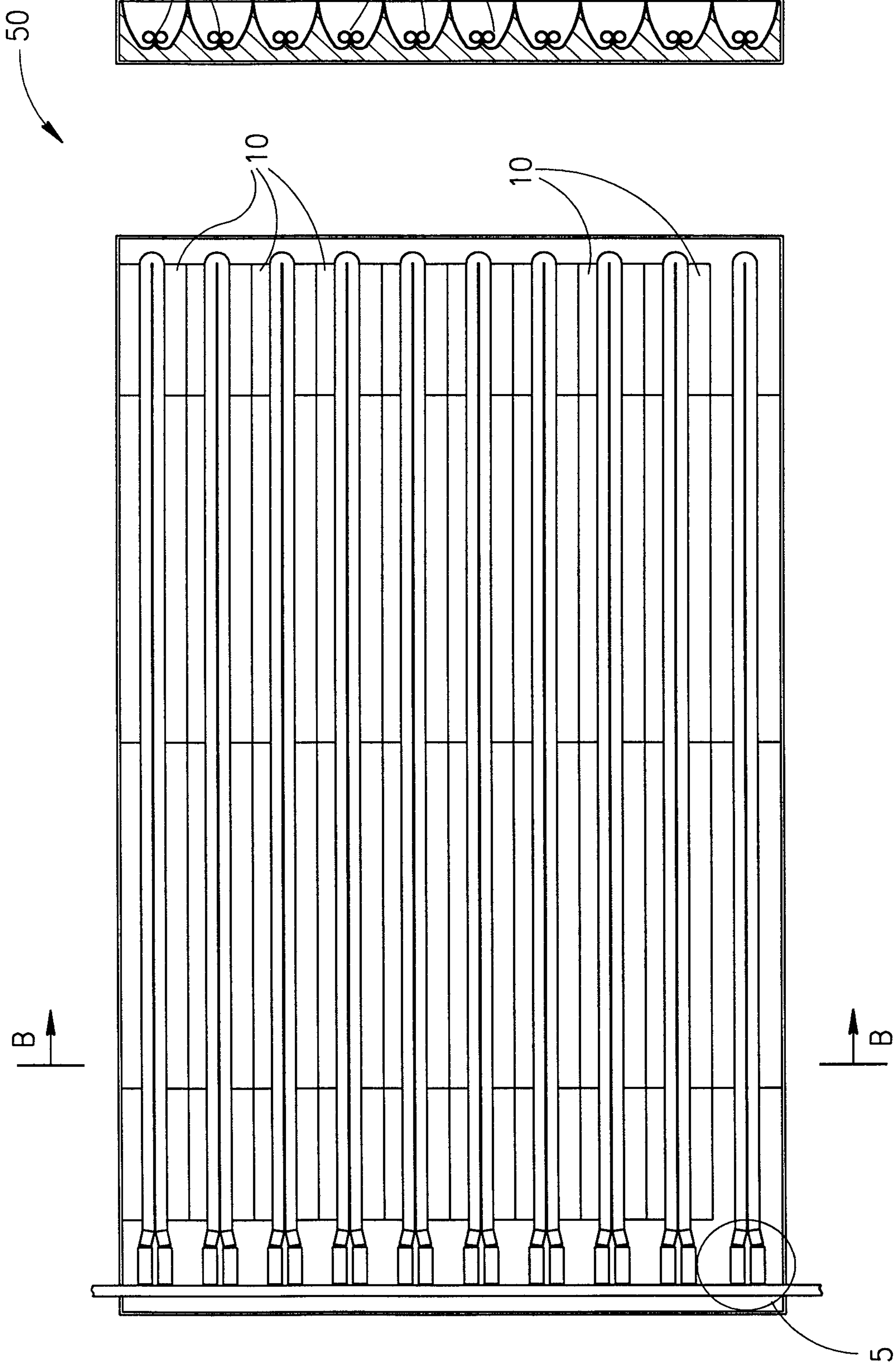


FIG.4A

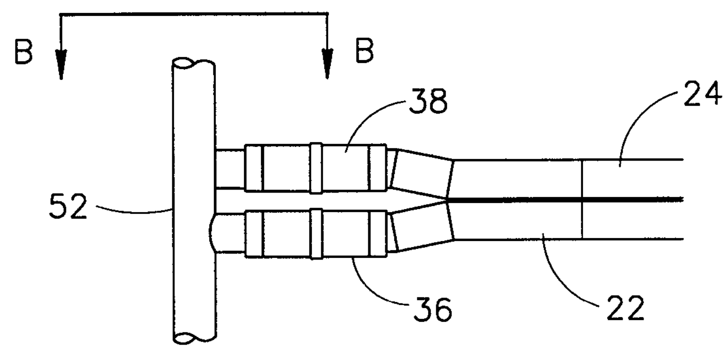


FIG.5A

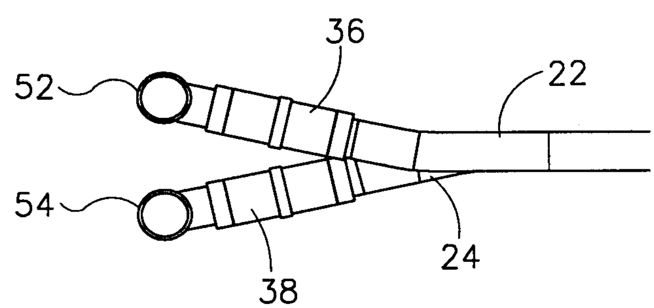


FIG.5B

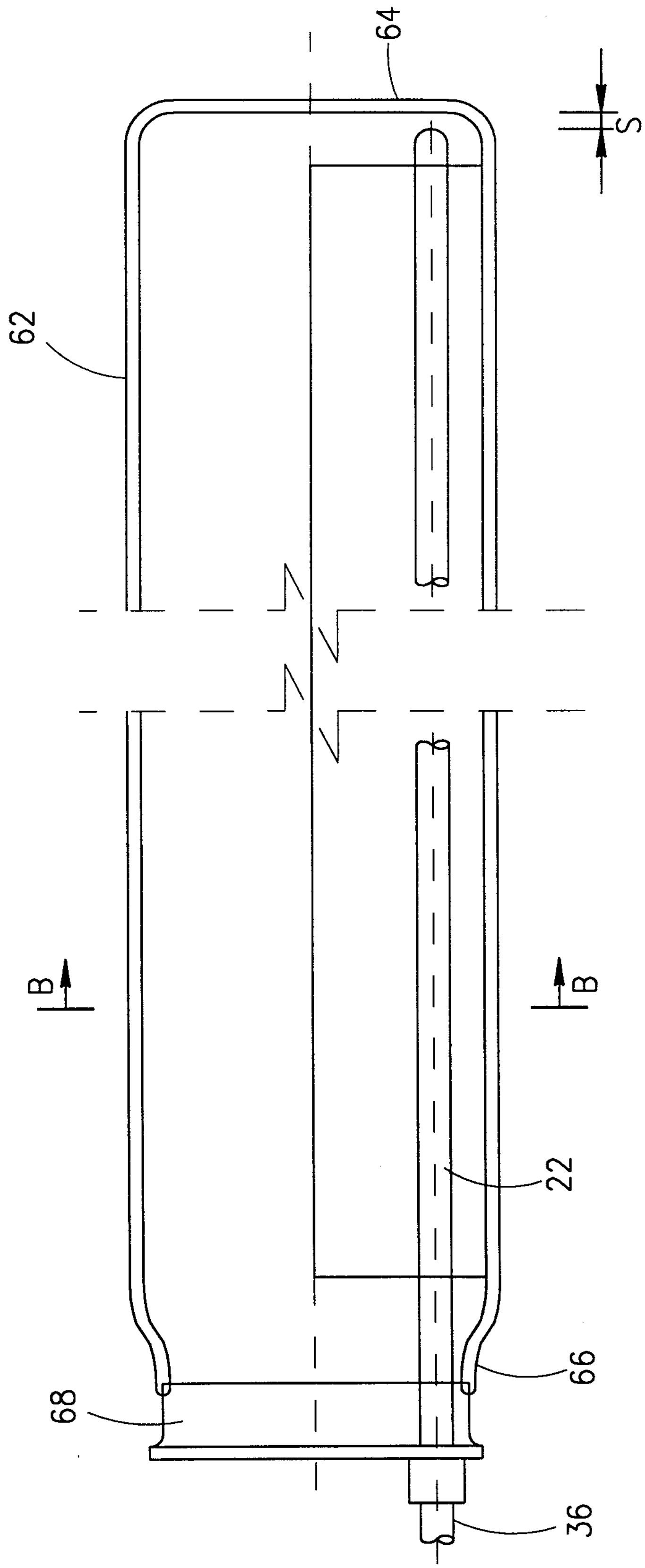


FIG.6A

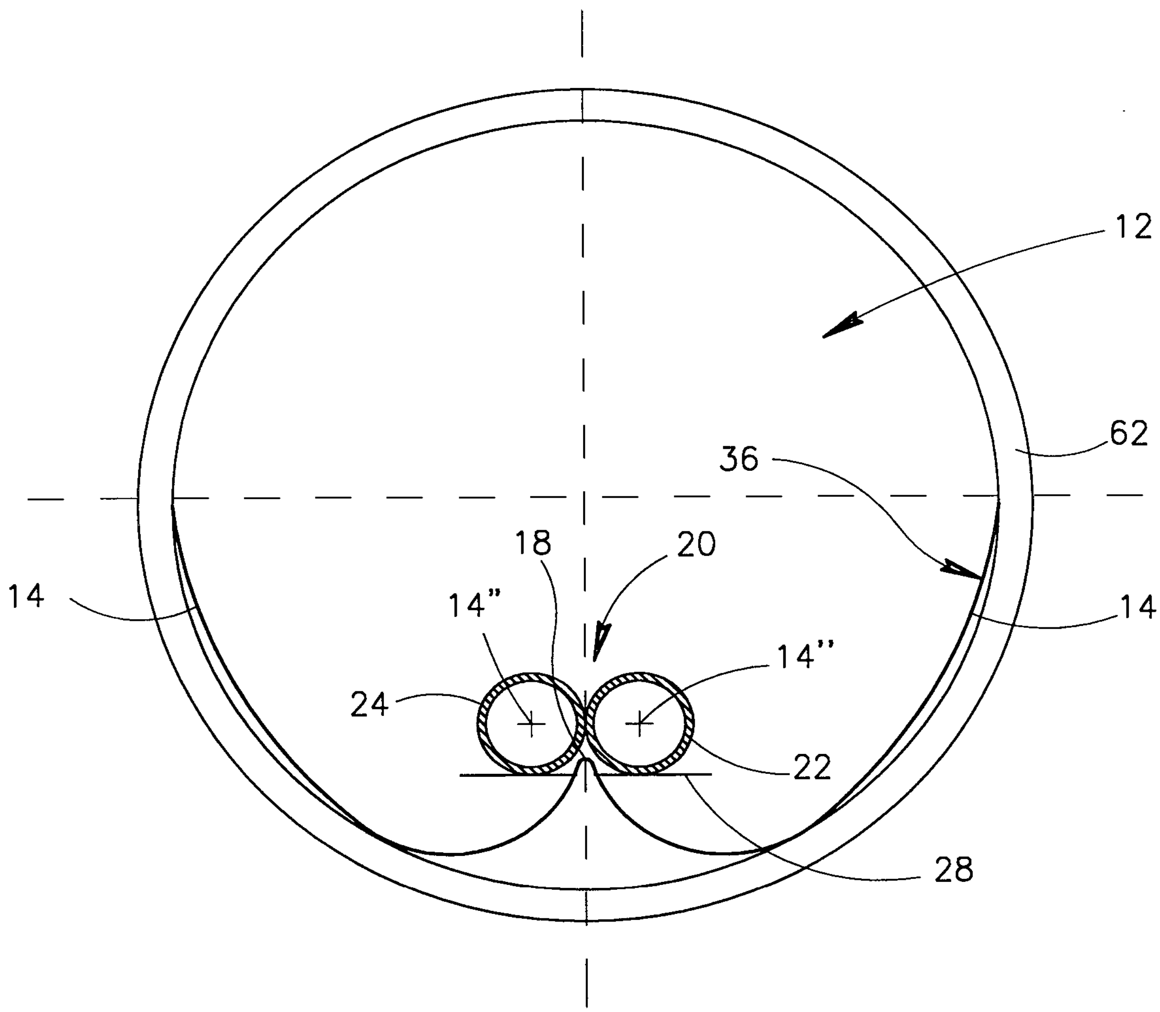


FIG.6B

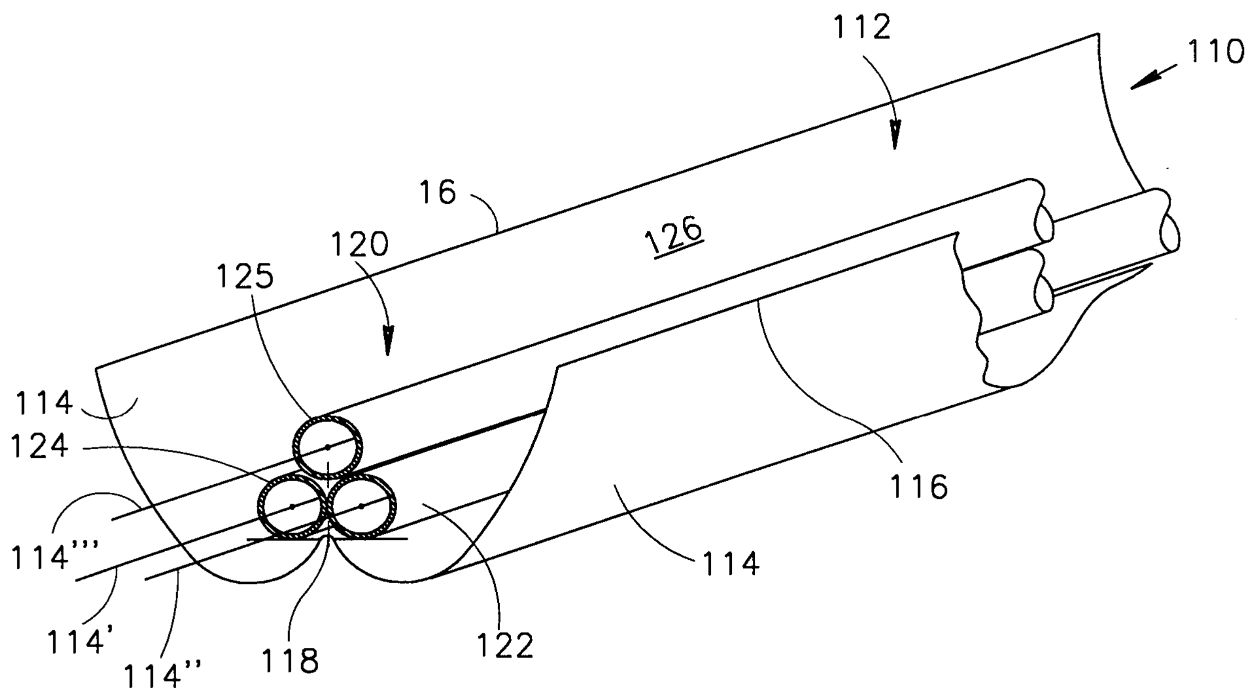
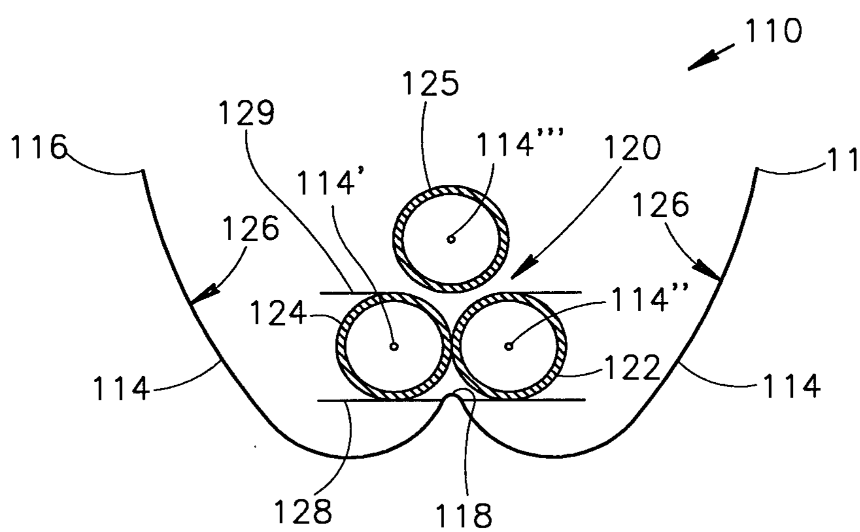

112
110
16
126
120
125
114
124
114'''
114'
114''
118
122
114
116

FIG.7A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125
129
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120
116
116
114'
126
126
124
114''
114
122
114
128
118

FIG.7B

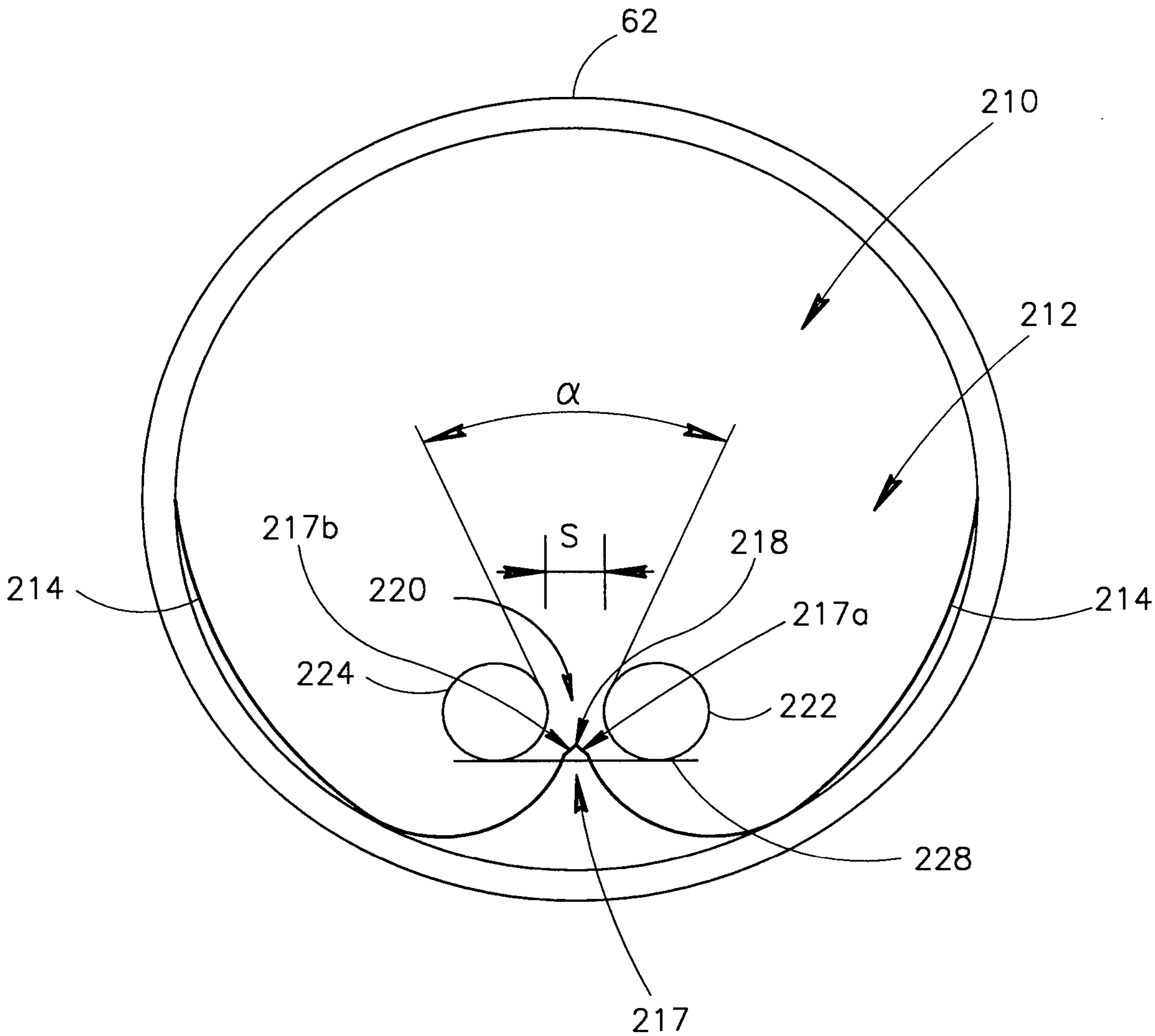

FIG.8